

HISTORIC AMERICAN ENGINEERING RECORD

16-FOOT TRANSONIC TUNNEL
BUILDING 1146

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER
HAMPTON, VIRGINIA

Submitted to:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER

Submitted by:

JAMES RIVER INSTITUTE FOR ARCHAEOLOGY, INC.

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HISTORIC AMERICAN ENGINEERING RECORD

NASA LANGLEY RESEARCH CENTER 16-FOOT TRANSONIC TUNNEL

HAER No. VA-118-E

Location: 11 West Taylor Street
National Aeronautical and Space Administration's (NASA) Langley
Research Center (LaRC), Hampton, VA.

UTM Coordinates of facility center point: E376958, N4105459

The 16-Foot Transonic Tunnel (TT), Facility No. 1146, is on the perimeter of the LaRC and adjacent to the Research center's boundary fence just to the west. Beyond the fence is Armstead Avenue (Virginia State Route 172). Because of its monumental scale and its tall air exchange tower, the TT visually dominates its view shed. Its location adjacent to a major public road gives it high visibility to the general public. Across West Taylor Street, to the east, are two, two-story red brick office buildings. To the north are driveways and an open area. South of the office building portion of the TT is a parking lot and south of the tunnel circuit is Facility No. 1241 that housed the TT's main drive equipment. Adjacent to 1241 is the Yorktown Road electrical substation (Facility No. 1243). The site is on the edge of the core of LaRC West Area and is characterized by a mixed collection of one and two story brick office/research facilities and test facilities of various designs and sizes, including other wind tunnels.

Date(s) of Construction: Completed 1941

Engineer: David J. Biermann and Lindsay I. Turner, Jr.

Present Owner(s): United States Government

Present Use: Vacant

Significance: When it was built in late 1941, the 16-Foot TT was not Langley's largest or fastest, but it facilitated important testing of military aircraft components and atomic bomb shapes during the war years. It played a significant role in the development of practical, large transonic and supersonic tunnels, and in the postwar evolution of tunnel design, accommodating early testing of the slotted-throat tunnel concept that allowed for transonic testing in a stable environment. Virtually every U.S. fighter aircraft design was tested in the tunnel during the Cold War era and beyond. The 16-Foot Transonic Tunnel is of national significance for its contributions to aircraft testing and design and the United States space program.

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The documentation was prepared with the assistance of a number of individuals including:

Matthew R. Laird, Ph.D., Senior Researcher
James River Institute for Archaeology, Inc.
223 McLaws Circle, Suite I
Williamsburg, Virginia 23185

Richard K. Anderson, Jr.
Cultural Resource Documentation Services
741 Bultman Drive, Suite 21
Sumter, South Carolina 29150-2555

Chris Cunningham, Photographer
Chris Cunningham Photography
5104 Caledonia Road
Richmond, Virginia 23225

Michael Newbill
3755 Oyster Point Quay
Virginia Beach, Virginia 23452

David H. Dutton
DUTTON+ASSOCIATES LLC
506 Coalbrook Drive
Midlothian, Virginia 23114

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Historical Background:

Early Wind Tunnel Research

Early experimenters in the field of human flight, including Leonardo da Vinci and Sir Isaac Newton, recognized the necessity of testing the aerodynamic characteristics of aircraft models, whether by propelling them through the air or by placing them in a moving airstream. As early as the eighteenth century, Benjamin Robins had developed the first mechanical "whirling arm" device to spin a test model through the air, a concept that was elaborated on by Sir George Cayley in the early nineteenth century. However, it was clear that these whirling arm devices created excessive turbulence that interfered with accurate testing. The result was the development of the wind tunnel, a device in which air could be moved past a stationary model under relatively controlled conditions.

A wind tunnel has five essential characteristics: it is comprised of an enclosed passage through which air is driven by a fan or other *drive system*. The heart of the wind tunnel is the *test section*, in which an aircraft *model* is supported in a carefully *controlled airstream*, which produces a flow of air around the model, duplicating that of a full-scale aircraft. The aerodynamic characteristics of the model and its flow field are then measured by appropriate balances and *test instrumentation*.

Francis H. Wenham, a Council Member of the Aeronautical Society of Great Britain, is widely credited with designing and operating the first wind tunnel in 1871, using a steam-powered fan to propel air through a tube. Most famously, Orville and Wilbur Wright used a wind tunnel of their own design to develop the glider prototype of the famous 1903 Wright Flyer, with which they performed the first powered aircraft flight at Kitty Hawk, North Carolina. Despite the success of the Wright brothers, however, it was European researchers who dominated the field of wind tunnel research in the years prior to World War I.¹

The Establishment of NACA and the Langley Memorial Aeronautical Laboratory

Recognizing that the U.S. was lagging considerably behind the Europeans in wind tunnel research, members of the American Aeronautical Society proposed at their inaugural meeting in 1911 that a national aeronautics laboratory be established. After several years of bureaucratic in-fighting, Congress finally created the National Advisory Committee for Aeronautics (NACA) in 1915, which was directed to "supervise and direct scientific study of problems of flight, with a view to their practical solution." In 1917, an aeronautical research facility and laboratory was established near Hampton, Virginia. Named for aviation pioneer Samuel P. Langley, the new Langley Memorial Aeronautical Laboratory (LMAL) began operation with relatively little experience in wind tunnel design or operation. In fact, its first operational tunnel, Wind Tunnel No. 1, was a direct copy of a British model which was already obsolete by the time it was completed in 1920.

¹ Donald D. Baals and William R. Corliss, *Wind Tunnels of NASA* (Washington, D.C.: National Aeronautics and Space Administration, 1981), 1-12.

By 1922, however, NACA made a tremendous leap forward in the field of aeronautical research with the completion of the Variable Density Tunnel (VDT), the first tunnel in the world to use the principle of variable density in pressure to accurately predict flow characteristics of scale model aircraft. When using small-scale models, engineers had to contend with "scale effects," as the flight characteristics of scaled-down versions could not be applied to full-sized aircraft without applying a correction factor. Scale effects could be addressed by proportionally varying air pressure in the tunnel, however, and the VDT was successfully used to test aircraft components. For example, research on airfoil sections conducted in the tunnel was used in the design of a number of famous aircraft, including the DC-3, B-17, and P-38.²

Despite its research value, the VDT could not evaluate the aerodynamic characteristics of a complete airplane, such as how rotating propellers affected aircraft control, nor could it adequately quantify the interference effects—or "drag penalties"—of various aircraft components such as external struts, wheels, and engine-cooling installations. In addition, aircraft test models had to withstand large forces and the strength of available materials limited their size. It was always possible to test actual aircraft in flight, but variations in atmospheric conditions required numerous flight checks to average the results. Given the current state of testing technology, the only alternative was to build a wind tunnel large enough to accommodate full-sized aircraft.

The first tunnel at Langley to accommodate full-scale aircraft components was the Propeller Research Tunnel (PRT), which became operational in 1927. Measuring 20 feet in diameter, the tunnel was large enough to test actual fuselages, engines, and propellers. Based on research conducted with the PRT, NACA engineers redesigned engine cowlings that dramatically reduced drag. Bolstered by the success of the PRT, NACA authorized the construction of the Full Scale Tunnel (FST) at Langley in February 1929. With the benefit of relatively low labor and material costs and a large pool of unemployed engineers, this Depression era project was completed in May 1931 at a cost of \$900,000. The largest wind tunnel in the world at that time, the enormous exterior structure measured 434 feet long, 222 feet wide, and 90 feet high. The test section measured 30 feet high by 60 feet wide and allowed the installation of aircraft with wingspans up to 40 feet. Early testing in the FST indicated unexpectedly high wind resistance caused by external aircraft components, prompting the government to send a steady stream of military aircraft to Langley for "drag cleanup tests."³

Origins of the 16-Foot High Speed Tunnel

In December 1938, the Special Committee on Future Research Facilities chaired by Rear Admiral Arthur Cook, chief of the Navy Department's Bureau of Aeronautics, recommended the construction of several new facilities at Langley geared toward investigating the special characteristics of military aircraft. One of these proposed

² Baals and Corliss, 12-19.

³ HAER, *NASA Langley Research Center, Full-Scale Wind Tunnel, VA-118-A* (Washington, D.C., U.S. Department of the Interior, 1995), 9-15.

facilities was a wind tunnel with a 16-foot diameter test section that could evaluate the cowling and cooling of full-sized aircraft engines and propellers. Approval for construction of this wind tunnel was granted in 1939, and a design was developed by David J. Biermann and Lindsay I. Turner, Jr.⁴

The 16-Foot High Speed Tunnel in World War II

The new 16-Foot High Speed Tunnel (HST) became operational on December 5, 1941, just two days before the Japanese attack on Pearl Harbor. The 16-Foot HST was located in the new West Area granted to the NACA by the War Department in 1939. Completed at an initial cost of \$1,422,000, the wind tunnel had an atmospheric, single-return circuit and a closed throat test section. The fan drive system was powered by a 16,000 horse power motor, and could develop a maximum speed of approximately 533 miles per hour. Special features included two dynamometers (2,000 hp and 6,000 hp) used in full-scale propeller testing.

With the onset of World War II, the pace of testing at the 16-Foot HST increased considerably. The new tunnel was used to evaluate the cooling problems plaguing the air-cooled engines that powered virtually every U.S. fighter and bomber aircraft. Ground testing could not duplicate high-speed airflow in and out of the engine nacelle, while testing in flight was costly and time consuming, and the aircraft could not accommodate adequate onboard instrumentation. The 16-Foot HST, however, could easily replicate subsonic high-speed flight conditions. Full-scale aircraft engines were mounted in the tunnel and operated at varying power levels while being monitored by hundreds of thermocouples, or temperature sensors. As heat problems were identified they could be modified immediately.

Despite its research capabilities, after two years of operation it had become apparent to Langley engineers that the tunnel had a number of shortcomings, particularly its tendency to choke above approximately 450 mph during tests of full-scale aircraft nacelles with operating engines and propellers. For this reason, testing of full-scale aircraft engines was halted in 1943. However, the 16-Foot HST continued to be used effectively for evaluating full-sized propellers, and even for testing shapes for the first atomic bombs.⁵

The Development of Slotted-Throat Tunnel Design

The 16-Foot HST was never Langley's largest or fastest wind tunnel, but it did play an important role in the postwar evolution of tunnel design. Early on, aeronautical engineers had recognized a significant flaw inherent in solid-walled test chambers, observing that the walls tended to suppress flow streamlines and produce deceptive aerodynamic effects. Reducing the size of aircraft models allowed for greater distance from the walls and raised the choking speed. However, this exacerbated the problem of "scale effects," as the flight characteristics of a model could not be applied to a full-sized aircraft without

⁴ Hansen, *Engineer in Charge: A History of the Langley Aeronautical Laboratory, 1917-1958* (Washington, D.C., National Aeronautics and Space Administration, 1987), 192, 464-66.

⁵ Baals and Corliss, 36-37; Hansen, 322.

applying a correction factor. The use of smaller models hampered the engineers' ability to evaluate the aerodynamic characteristics of a complete airplane, such as the interference effects—or “drag penalties”—of various components such as external struts, wheels, and engine-cooling installations. Aircraft test models had to withstand large forces and the strength of available materials also limited the extent to which they could be reduced in size.

Researchers already had theorized that this interference problem of interference might be counteracted by placing slots in the test section throat which would reduce the blockage effect caused by the tunnel walls, and some experimental configurations had been tested. However, Langley physicist Ray H. Wright was the first to engineer a practical application for this concept, which came to be known as “slotted-throat” or “slotted-wall tunnel” design. Because the introduction of slots into the design would require a proportional increase of power, Wright focused on analyzing the most efficient size of the slots to achieve zero blockage. After a tedious series of calculations, he determined that the optimal peripheral openness of the 8-Foot HST was about 12 percent, which was significantly less than earlier experimenters had been working with.

Based on this work, Wright's division chief, John Stack, took up the cause of slotted-throat testing, and—despite considerable skepticism—succeeded in persuading NACA to allocate funding and personnel to the problem. The first team of researchers investigating the slotted-throat tunnel configuration began testing in the 16-Foot HST early in 1947. The facility was chosen primarily because an earlier program already had been investigating blocking corrections in small, circular, “parasitic” test sections operating off the main tunnel. Initial tests in a slotted tunnel running off the 16-Foot HST produced a maximum speed just under Mach 1 (the speed of sound, approximately 761 mph at sea level) before choking. At this point, the engineers had the idea of removing the slotted-throat tunnel model from the parasitic test section and turning up the power of the driving fan. When they did, they found that the small experimental tunnel easily reached and surpassed the speed of sound. News of this finding spread quickly throughout the Langley wind tunnel community, and confirmed that the slotted wall design could produce transonic wind speeds.

Although testing in the 16-Foot HST was crucial in the advance of slotted-throat tunnel technology, ironically it would not be the first tunnel converted to this design; this honor went instead to the older 8-Foot High Speed Tunnel, which was operating as a transonic tunnel in October 1950. By December, however, the 16-Foot HST had been retrofitted with a new 14-foot octagonal slotted-test-section throat, a new control room, air filters in the air exchange system, and acoustical treatments. The tunnel was repowered to 60,000 hp with two counter-rotating fans, and with its new high-speed capabilities it was redesignated the 16-Foot Transonic Tunnel (TT).⁶

⁶ Hansen, 320-24; Francis J. Capone et al., *The NASA Langley 16-Foot Transonic Tunnel: Historical Overview, Facility Description, Calibration, Flow Characteristics, and Test Capabilities* (Washington, D.C., NASA, 1995), 1; NACA, *Characteristics of Nine Research Wind Tunnels of the Langley Aeronautical Laboratory* (Washington, D.C., NACA), 1-15; Baals and Corliss, 63..

The Cold War Era and Beyond

The utility of the 16-Foot TT continued through the Cold War era and beyond, with virtually every U.S. fighter design undergoing testing in the tunnel, including the F-14 Tomcat, F-15 Eagle, F-18 Hornet, and F-117 Nighthawk, as well as the B-1 Spirit bomber and B-58 Hustler, the Apollo moon mission spacecraft, the Space Shuttle, the X-33 VentureStar space vehicle, and the Navy Advanced Technology Fighter (NATF). The tunnel also supported experimental programs such as the Highly Maneuverable Aircraft Technology (HiMAT) and the Joint Advanced Strike Technology (JAST).

In order to keep pace with increasing technological demands, a new 35,000 hp plenum section blower was added to the 16-Foot TT in 1969. A major rehabilitation in 1977 included the installation of new fan blades, tunnel controls and associated control room equipment, on-site data acquisition capabilities, and a new computer system. In 1989-90, several significant modifications were made to improve test-section flow characteristics, including a new model support system, new fan blades, a catcher screen on the first set of turning vanes, new data acquisition and computer systems, as well as process controllers to control tunnel speed and the attitude and jet flow of powered models.

With the end of the Cold War came a diminishing number of new aircraft designs, and the National Aeronautics and Space Administration (NASA) was faced with a surplus of tunnels across the country. In response, the agency implemented a full-cost accounting measure that required research centers to charge customers for a portion of the overhead of running the facilities. Under the Wind Tunnel Enterprise program established in 1994, the 16-Foot TT provided testing facilities to clients in private industry such as Boeing, covering its \$10 million annual operating budget with customer fees. In 2004, the Rand Corporation presented an assessment of wind tunnel and propulsion test facilities to NASA and the Office of the Secretary of Defense. This report concluded that the 16-Foot TT represented a "borderline case." Although affordable and well utilized, it was deemed "technically weak," with its capabilities inferior to those of other facilities. Based on this recommendation, NASA closed the facility in 2004.⁷

Buildings 1146A-C and G-M, 16-Foot High Speed/Transonic Tunnel Facility NASA LaRC: The following buildings and structures were added to the 16-Foot TT over an approximately 40 year period in response to changes in equipment and testing requirements as well as an increase in general administrative and storage space. The physical relationship of these facilities to the 16-Foot TT is further illustrated in the detailed line drawings.

Building 1146A: TWT Equipment Facility

This facility is comprised of a 4,404-square-foot equipment building constructed in 1959.

⁷ Capone et al., 2,8; Wind Tunnel Enterprise, Langley 16-Foot Tunnel Brochure, 2004; Philip S. Anton et al., *Wind Tunnel and Propulsion Test Facilities: An Assessment of NASA's Capabilities to Serve National Needs* (Arlington, Virginia, Rand Corporation), 69.

Building 1146B: TWT Valve House

This facility is comprised of a 140-square-foot valve house constructed in 1959.

Building 1146C: TWT Cooling Tower Pump House

This facility is comprised of a 1,524-square-foot cooling tower pump house constructed in 1955.

Building 1146G: TWT Gas Storage Shed

This facility is comprised of a 76-square-foot gas storage shed constructed in 1995.

Building 1146H: TWT Motor House #1

This facility is comprised of a 3,218-square-foot motor house constructed in 1995.

Building 1146I: TWT Motor House #2

This facility is comprised of a 3,111-square-foot motor house constructed in 1995.

Building 1146J: TWT Complex Annex

This facility is comprised of a 486-square-foot annex constructed in 1995.

Building 1146K: TWT Air Exchange Tower

This facility is comprised of a 4,467-square-foot air exchange tower constructed in 1995.

Building 1146L: TWT Complex Annex

This facility is comprised of a 127-square-foot annex constructed in 1995.

Building 1146M: TWT Complex Access Area

This facility is comprised of an 86-square-foot access area constructed in 1995.

Chronology:

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| 1938 | The Special Committee on Future Research Facilities recommends construction of a wind tunnel at Langley with a 16-foot-diameter test section. |
| 1941 | Construction is completed and the new 16-Foot High-Speed Tunnel (HST) becomes operation on December 5, 1941, only two days before the Japanese attack on Pearl Harbor. |
| 1943 | Testing of full-scale aircraft engines in the tunnel is suspended due to technical problems. |
| 1950 | The tunnel is retrofitted with the new slotted-throat design, allowing for transonic wind speeds and is re-designated the 16-Foot TT. |
| 1969 | A new 35,000 hp plenum section blower is added. |
| 1977 | A major rehabilitation includes the installation of new fan blades, tunnel controls and associated control room equipment, on-site data acquisition capabilities, and a new computer system. |
| 1990 | A second comprehensive rehabilitation includes installation of a new model support system, fan blades, a catcher screen on the first set of turning vanes, new data acquisition and computer systems, and process controllers to control tunnel speed and the attitude and jet flow of powered models. |
| 1994 | The facility is first opened to research by private industry clients under NASA's Wind Tunnel Enterprise program. |
| 2004 | A Rand Corporation report recommends that the 16-Foot TT is "well utilized but technically weak," and NASA closes the facility. |

Sources Consulted:

- Anton, Philip S., Eugene C. Gritton, Richard Mesic, Paul Steinberg et al. *Wind Tunnel and Propulsion Test Facilities: An Assessment of NASA's Capabilities to Serve National Needs*. Arlington, Virginia: Rand Corporation, 2004.
- Baals, Donald D. and William R. Corliss. *Wind Tunnels of NASA*. Washington, D.C.: National Aeronautics and Space Administration, 1981.
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- Capone, Francis J., Linda S. Bangert, Scott C. Asbury, Charles T. L. Mills, and E. Anne Bare. *The NASA Langley 16-Foot Transonic Tunnel: Historical Overview, Facility Description, Calibration, Flow Characteristics, and Test Capabilities*. Washington, D.C.: National Aeronautics and Space Administration, TP-3521, 1995.
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- National Advisory Committee for Aeronautics (NACA). *Characteristics of Nine Research Wind Tunnels of the Langley Aeronautical Laboratory*. Washington, D.C.: NACA, 1957.
- Wind Tunnel Enterprise. Langley 16-Foot Transonic Tunnel Brochure, <<http://wte.larc.nasa.gov/facilities/aerodynamics/16foot.cfm>>. Hampton, Virginia: NASA Langley Research Center, 2004.

Physical Description:

Construction commenced on February 11, 1939 and was completed in 1941; operations began on Friday, December 5, 1941. The purpose of this wind tunnel was to investigate various aerodynamic problems of airplanes, including cowling and cooling of full-size engines and propellers, at high speeds. Key design team members were David J. Biermann and Lindsey I. Turner, Jr. The facility was closed in 2004 after 65 years of use. An essentially twin wind tunnel to the TT exists at the NASA Ames Research Center, Moffett Federal Airfield, Mountain View, California.

The TT's tunnel circuit is a tubular structure that forms an elongated rectangle in plan view with four 90-degree corners. The airflow is counterclockwise. The tunnel tube is a steel structure on the south end and on the east and west sides. Attached to the outside of the steel tube is an exposed frame composed of steel members that ring its circumference and horizontal steel members that engage the circumferential members. The steel tube is supported by a combination of steel columns, braces and frames. The circuit's overall dimensions in plan, excluding the office building that extends to the west side, are approximately 382 feet (north-south) by 143 feet (east-west). It is elevated above the ground; the centerline of its horizontal axis is approximately 35 feet above grade. The test section is on the east side and is contained in a concrete building. The tube increases in diameter along the west side from the test section to the drive fan section. It maintains a constant diameter through the drive fan section at the north end. Its diameter increases again along the length of the return section on the west side from the drive fan section to the ventilation section. Through the south end it maintains its maximum interior diameter of 58 feet. The power section and drive fans are housed in a massive concrete structure at the north end of the tunnel. A pair of 30,000-horse power electric motors drives two counter-rotating fans. The drive motors are located outside of the tunnel on two very large concrete pedestals. These pedestals project to the east and west from the fan section and curved steel roofs cover the drive motors. Turning vanes are located in each of the four corners of the tunnel. The tube penetrates the air exchange section, a large tower on the west side of the tunnel near its south end. A ventilation penthouse with continuous louvers on each of its four sides projects beyond the walls of the tower. The air exchange tower is the tallest element of the wind tunnel complex. The quiescent chamber is on the east side of the tunnel between an anti-turbulence screen near the south end of the tunnel and the entrance cone of the test section. A large tubular steel duct connects the test section to the air compressor in the air removal building. The air removal building is located between the tunnel tubes just south of the fan section. This building, clad with corrugated aluminum panels, also contains labs and a ceramic spray shop. Minor structures at the site supporting the tunnel's operation and built in 1941 include a high-pressure air station, a valve house and a high power air station. A cooling tower and pump house date from 1955, and the air removal building was built in 1959.

The summary description in the following paragraph is abbreviated and excerpted in portions or paraphrased from The NASA Langley 16-Foot Transonic Tunnel, Historical

Overview, Facility Description, Calibration, Flow Characteristics, and Test Capabilities,
NASA Technical Paper 3512, September 1995.

General Description The Langley 16-Foot Transonic Tunnel is a closed circuit single-return atmospheric wind tunnel that has a slotted transonic test section with a Mach number range of 0.1 to 1.3. Test section plenum suction is used for speeds above a Mach number of 1.05. The major components of the tunnel are the quiescent chamber, entrance cone, test section, diffuser, power section, return passage, and air exchange section. The length of the tunnel circuit is 930 feet. The test section is a rectangular octagonal cylinder with a cross section area less than half that of a 16-foot circle. The top half of the test section is removable. Four sets of turning vanes are located at the 90-degree elbows in the tube. The tunnel has three screens, one is in the air exchange section, another is in the quiescent chamber, and one is on the first set of turning vanes. The test-section air removal equipment is located outside the tunnel between the diffuser and the return passage. The entrance cone incorporates a transition from circular to octagonal cross sections and includes a slowly converging entrance liner that terminates at the upstream end of the test section. The cross section of the throat is a closed regular octagon with an area of 199.15 square feet. The feature that gives the wind tunnel transonic capability is the venting of the test section to the plenum. In this tunnel the vents are eight longitudinal slots that are located at the intersection of the wall flats and provide a 3.9-percent open periphery. The plenum is a sealed tank 32 feet in diameter, which encloses the test section and the entrance diffuser.

Test Section Walls The test section wall is made up of eight longitudinal flats symmetrically located about the tunnel centerline. The surface of each flat is a continuous, machined steel plate with a width of 66.50 inches. Long metal strips are attached to the sides of each of the flats to form the longitudinal slots. The steel plates that form the walls are attached rigidly to the tunnel structure.

Transonic Slots The test-section transonic slots, which are located at the intersections of the wall flats, are eight longitudinal openings that are generally parallel to the tunnel centerline. These slots provide vents between the test-section airstream and the plenum that surrounds the test section.

Diffuser Entrance Vanes The purpose of the diffuser entrance vanes and lips is to reintroduce the low energy axial flow that exists in the plenum adjacent to and at the downstream end of the slots into the tunnel airstream. The diffuser entrance vanes and lips are adjustable as a unit to form a part of the tunnel wall that closes the openings between the plenum and the airstream in the region where the downstream end of the slots would otherwise extend into the diffuser.

Windows and Access Hatches Two windows 6 feet long and 3 feet high are centered in two wall flats of the test cell. In line with these windows are others of equal size in the walls of the plenum. The windows are used primarily for model

observation and flow visualization. The model installation hatch was made unusually large to permit use of a hoist required for handling heavy loads. The upper 3/8 of the plenum, together with the upper three flats of the test cell, can be raised and moved as a unit. The open hatch is 15.5 feet wide and 52 feet wide.

Diffuser The diffuser extends from the downstream end of the test cell to the power section. The diffuser decelerates the air stream after it passes through the test section to convert as much kinetic energy as possible into pressure energy.

Electric Motors The two main drive motors are each connected directly to one of the drive fans by a 60-foot long shaft. Each is rated for continuous operation at 23,000-hp at a rotational speed of 340 rpm, for two hours of operation at 30,000-hp at 366 rpm, and for 1/2 hour of operation at 34,000-hp at 372 rpm. Motor controls permit continuous variations in rotational speed from 60 rpm to 372 rpm.

Drive Fans The drive fans constitute a two-stage axial-flow compressor with two sets of counter rotating blades and no stator blades. The fans are 34.0 feet in diameter with less than 0.2 in radial clearance between blade tip and tunnel wall. The fan blades are made of laminated Sitka spruce with frangible foam tips. The upstream fan has 25 blades and the downstream fan has 26 blades. The axial space between the two fan hubs is occupied by a floating spinner 8.0-ft long and 20 ft in diameter, which represents a continuation of the shaft enclosure contour. This spinner is supported on bearings housed in the ends of the fan drive shafts and is restrained from rotating by four small rods.

Return Passage The return passage upstream of the air exchange section is a large conical diffuser and downstream, a cylinder. The return passage primarily ducts reenergized air from the power section through the air exchange section back to the quiescent chamber. Air velocities throughout the return passage are too low to yield much pressure recovery in the diffuser portion of the return passage. The cylindrical portion has two 90-degree elbows, which incorporate the third and fourth sets of turning vanes.

Air Exchange Section The air exchange section cools the wind tunnel airstream and scavenges exhaust gases when operating engines are under investigation in the test section. All energy introduced through the main drive fans is eventually converted into heat, which elevates the airstream temperature. With no cooling of the wind tunnel during operation at high power, the airstream temperature would increase rapidly to levels that would exceed 175 degrees Fahrenheit, which is the temperature limit imposed by the wooden fan blades. The process of cooling by air exchange allows exhausting a part of the wind tunnel airstream that has become heated and may contain exhaust gases. The heated air is replaced with cool ambient air. The air exchange section that performs this function is basically a constriction in the return passage with exhaust and intake openings located, respectively, upstream and downstream of the constricted cross section. Both exhaust and intake openings are

essentially annular and have 36 segments equipped with adjustable louvers. The interconnected intake louvers are manually adjustable and are generally left in an open position. The interconnected exhaust louvers are mechanically actuated, and heated air exhaust is quickly adjusted during a test for partial control of airstream stagnation temperature. Air exchange can be varied between 5 and 20 percent of the tunnel mass flow. When test-section air is removed, the air exchange intake mass flow exceeds the exhaust by the amount being removed from the test-section plenum. The air exchange section is housed in a rectangular tower with baffles that duct the heated exhaust out of the top of the tower while cool air is taken in at the sides near the top. Dust is removed from the intake air by filters. In both intake and exhaust, acoustic baffles are used to attenuate noise.

Screens The circuit of the 16-Foot Transonic Tunnel has three screens. Two antiturbulence screens, each composed of a single layer of square mesh woven wire, are installed in the tunnel. One screen is installed in the air exchange section and the other is in the quiescent chamber. In addition to reducing turbulence, the screen in the air exchange section also increases the effectiveness of the air exchange by creating a slight pressure drop between exhaust and intake. A catcher screen was installed at the first set of turning vanes in 1990. The purpose of this screen is to stop most of the debris that may occur due to model failures and prevent them from striking the fan blades.

Air Removal System The air removal system consists of a large motor-driven axial-flow compressor that removes low energy air (up to 4.5 percent of test-section mass flow) from the plenum surrounding the test section and discharges this air to the atmosphere. Test-section air removal is used to obtain low supersonic speeds in a transonic wind tunnel. Properly sized longitudinal slots in a test-section wall and the plenum around the test section serve to reduce or eliminate solid blockage of a model, and thereby permit tests of the model at supersonic speed without choking the airstream at the station of model maximum cross-sectional area. The low static pressure in the vicinity of the diffuser entrance is transmitted through the slots at their downstream end and into the plenum. Thus, a low static pressure corresponding to a supersonic speed is established in the plenum. Because air in the plenum is relatively stagnant, the low pressure in the plenum is exerted directly through the slots and the test-section boundary layer to the test-section airstream along the full length of the slots. Without test-section air removal, the maximum supersonic speed in a slotted or vented test section is limited by the power of the tunnel main drive. Without air removal, the maximum Mach number in the 16-Foot Transonic Tunnel was 1.08. For test-section air removal, the compressor is sized to pump stagnant air from the plenum and exhaust it to the atmosphere. The air removal compressor is a nine-stage axial-flow compressor rated as 36,000-hp. The throat area is 36.6 square feet. The compressor is driven by a wound rotor induction motor through a gearbox. The drive and pinion gears have 328 and 79 teeth, respectively. These gears have a ratio of compressor to motor speed of approximately 4.15. The motor rating is 36,000-hp at

552 rpm. Speed is controlled by a slip regulator that incorporates a brine tank rheostat.

Wind Tunnel Support Areas

Control Room The control room is located on the second floor of the wind tunnel building in an area that is behind and below flat 6 of the test section. All functions associated with a test, such as tunnel air speed, model attitude, and compressed air for propulsion tests are controlled from this room. Depending on the test, three or four operators are required for operation. All the computer systems necessary for tunnel operation, data acquisition, and off-line data processing were located within this room, but have now been removed.

Model Preparation Area The model preparation area (MPA) allows pretest buildup and complete calibration of propulsion models. The MPA consists of two rooms, which comprise a calibration bay area with a 10.75-foot-high ceiling and a control room. The area is completely enclosed, and thus provides physical security for most test requirements. The MPA is located within the wind tunnel building underneath the wind tunnel.

Attached to the east side of the test section building is a two-story red brick office and shop building. When the facility was built in 1941 it consisted of a 3 bay by 13 bay, two-story building with a one-story front section (two bays by nine bays) extending to the east toward West Taylor Street. Adjacent to the test section building was a brick elevator penthouse that projected two stories above the roof. The building had a flat roof surrounded by a parapet. The exterior walls were red brick laid in American bond (headers every 6th course) above an exposed concrete foundation. A cast stone coping above a cast stone belt course capped the parapet. Windows, grouped in pairs, were double-hung wood with three vertical lites. Sills were cast stone and headers were corbelled brick four courses high. The front entrance featured a pair of glazed doors surrounded by brick pilasters that projected approximately four inches beyond the primary wall surface. The pediment was on the plane of the pilasters. A cast stone cornice capped the brick pediment. Brick wall panels below first floor windows and between first and second floor windows were recessed approximately four inches from the face of brick pilasters between windows. The original floor plan of this building is unknown, but it is probable that offices were located in the one-story element, while the two-story portion was mostly shop or lab space. A large service elevator located at the rear of this building served the test section.

Two-story additions were placed on the north and south ends of building. Each addition was 2 bays wide (north-south) by 3 bays deep (east west). The west walls of these additions were 1 bay beyond the west wall of the original building. Architecturally, they matched the design of the original. Their date of construction appears to have been in 1973 although the records are unclear. A second, major addition was undertaken in 1992. This project resulted in the addition of 6,900 square feet of gross floor area and included

demolition within the first and second floors, demolition of front and side entrances, and expansion of both the first and second floors. Construction included a new second floor above the one story office and continued with a two story expansion that projected six feet to the west of the prior additions. A new two-story entrance element was symmetrically placed on the new west wall. Again, the design and materials matched the architectural features of the prior designs except for black anodized windows with two tinted fixed glass lites above an awning sash. Offices are concentrated in the front of the rehabilitated and expanded building and labs and shops occur primarily in the rear. The elevator penthouse and service elevator were retained. The interior of the building features vinyl composition tile floors, carpet, painted plaster or gypsum board walls and partitions, and suspended acoustical tile ceilings.

Even after major improvements in the wind tunnel, additions to the brick office building, and removal of control room equipment, this facility retains good integrity of association, location, setting, design, feeling, material and workmanship.

HISTORIC AMERICAN ENGINEERING RECORD

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NASA LANGLEY RESEARCH CENTER
16-FOOT TRANSONIC WIND TUNNEL
Hampton
Virginia

HAER NO. VA-118-E

Chris Cunningham, photographer, March 2006

VA-118-E-1	VIEW OF 16-FOOT TRANSONIC WIND TUNNEL LOOKING SOUTH-SOUTHWEST
VA-118-E-2	VIEW OF 16-FOOT TRANSONIC WIND TUNNEL LOOKING NORTHEAST
VA-118-E-3	VIEW OF 16-FOOT TRANSONIC WIND TUNNEL LOOKING WEST-NORTHWEST
VA-118-E-4	VIEW OF 16-FOOT TRANSONIC WIND TUNNEL LOOKING NORTH
VA-118-E-5	DETAIL VIEW OF 16-FOOT TRANSONIC WIND TUNNEL LOOKING NORTH
VA-118-E-6	VIEW OF 16-FOOT TRANSONIC WIND TUNNEL LOOKING SOUTHEAST
VA-118-E-7	Photocopy of photograph (original in Langley Research Center Archives, Hampton, VA [LaRC] (EL-2002-00169) VIEW OF 16-FOOT TRANSONIC WIND TUNNEL UNDER CONSTRUCTION CA. 1940.
VA-118-E-8	Photocopy of photograph (original in Langley Research Center Archives, Hampton, VA [LaRC] (EL-2002-00177) VIEW OF 16-FOOT TRANSONIC WIND TUNNEL UNDER CONSTRUCTION CA. 1940.
VA-118-E-9	Photocopy of photograph (original in Langley Research Center Archives, Hampton, VA [LaRC] (EL-2002-00285) VIEW OF 16-FOOT TRANSONIC WIND TUNNEL CONTROL ROOM SHOWING CAMERA STANDS.

VA-118-E-10	Photocopy of photograph (original in Langley Research Center Archives, Hampton, VA [LaRC] (L-64729) VIEW OF 16-FOOT TRANSONIC WIND TUNNEL LOOKING SOUTHWEST CA. 1942.
VA-118-E-11	Photocopy of photograph (original in Langley Research Center Archives, Hampton, VA [LaRC] (EL-2002-00193) VIEW OF 16-FOOT TRANSONIC WIND TUNNEL UNDER CONSTRUCTION CA. 1941 LOOKING SOUTH-SOUTHWEST.
VA-118-E-12	Photocopy of photograph (original in Langley Research Center Archives, Hampton, VA [LaRC] (EL-2002-00212) VIEW OF 16-FOOT TRANSONIC WIND TUNNEL OFFICE AND LABORATORY BUILDING UNDER CONSTRUCTION CA. 1941 LOOKING SOUTH- SOUTHWEST.
VA-118-E-13	Photocopy of photograph (original in Langley Research Center Archives, Hampton, VA [LaRC] (EL-1997-00102) INTERIOR VIEW OF 16-FOOT TRANSONIC TUNNEL SHOWING TURNING VANES CA. 1990.
VA-118-E-14	Photocopy of photograph (original in Langley Research Center Archives, Hampton, VA [LaRC] (EL-1997-00111) INTERIOR VIEW OF 16-FOOT TRANSONIC WIND TUNNEL SHOWING FAN BLADES CA. 1990.
VA-118-E-15	Photocopy of photograph (original in Langley Research Center Archives, Hampton, VA [LaRC] (EL-1997-00103) INTERIOR VIEW OF 16-FOOT TRANSONIC WIND TUNNEL CA. 1990.

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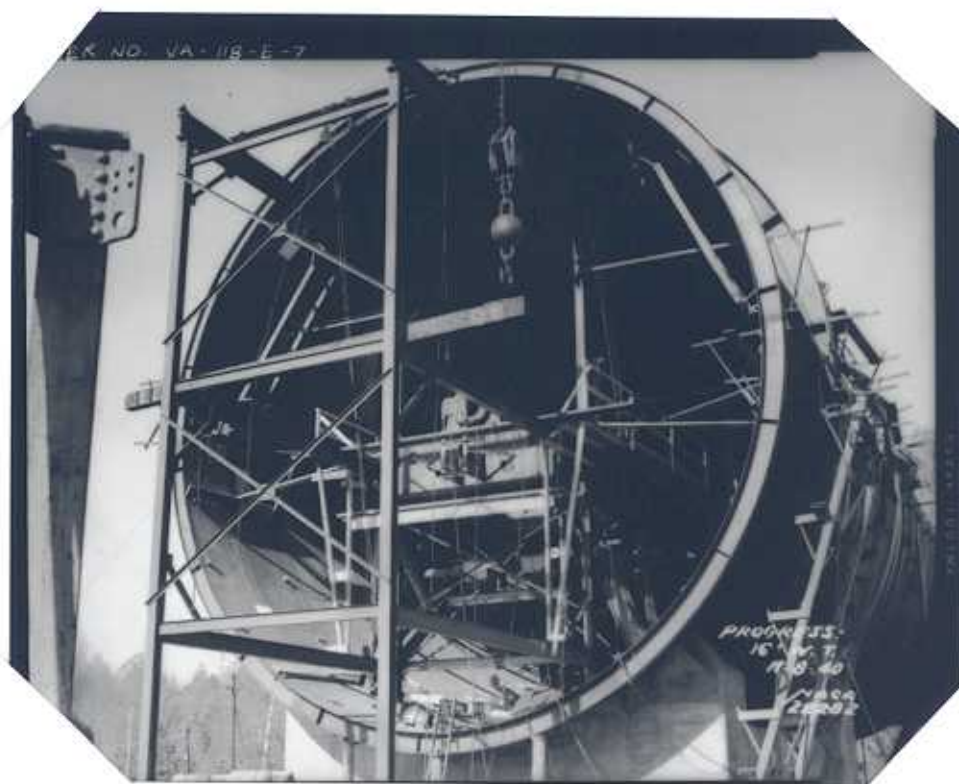
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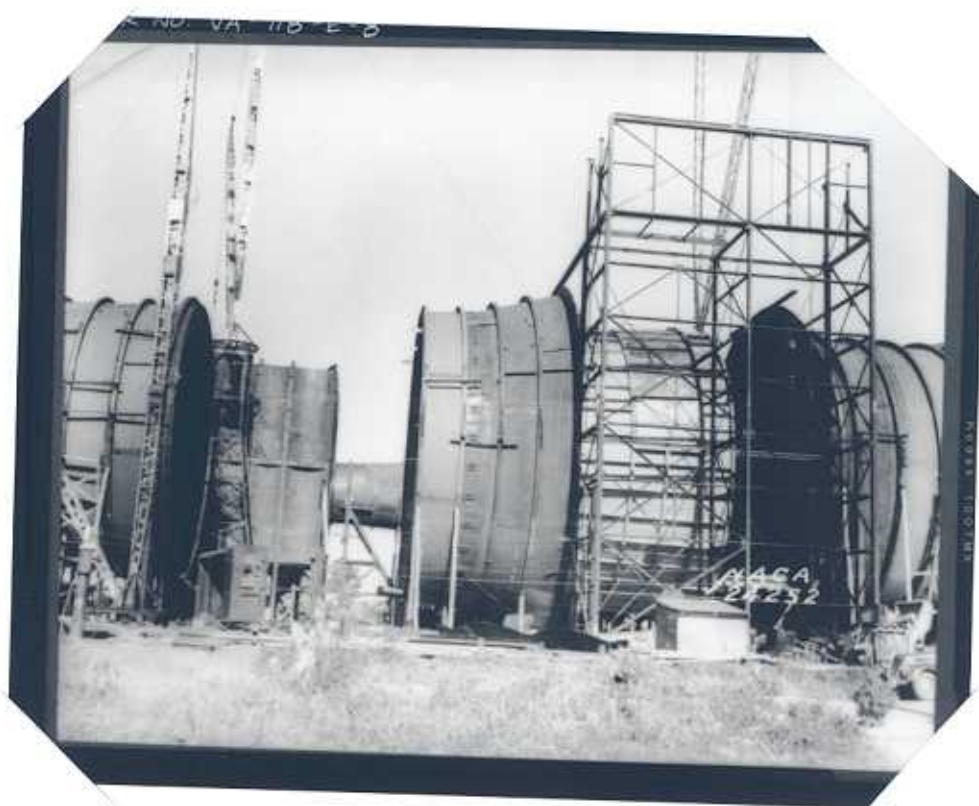
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HAER NO. VA-118-E-13



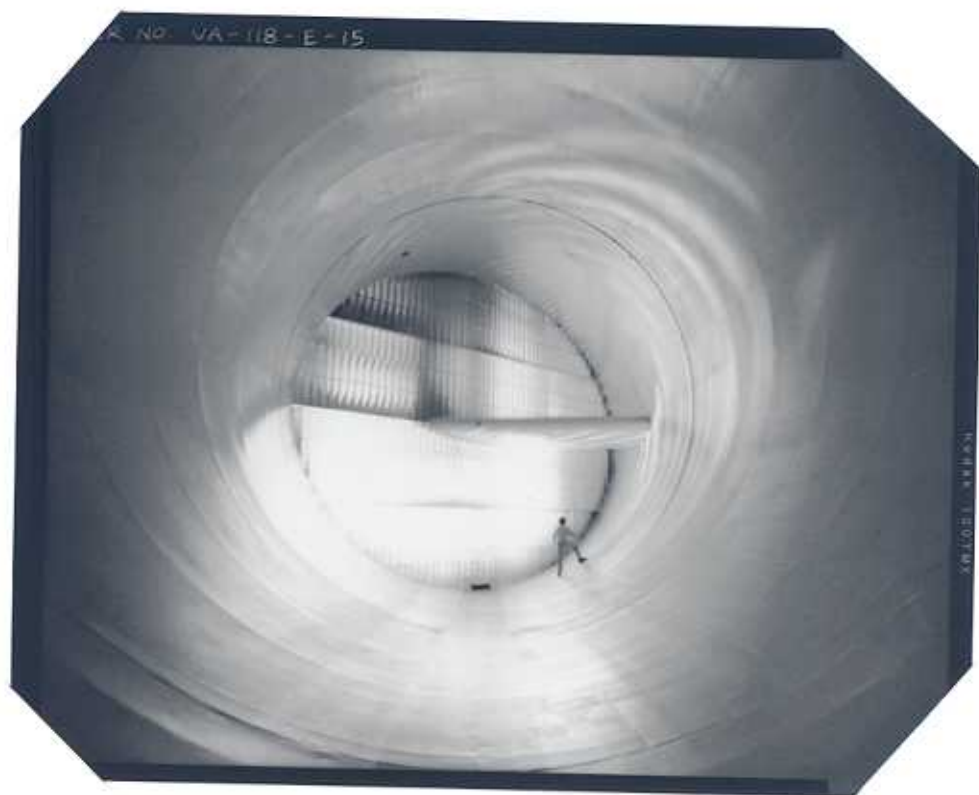
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TUNNEL

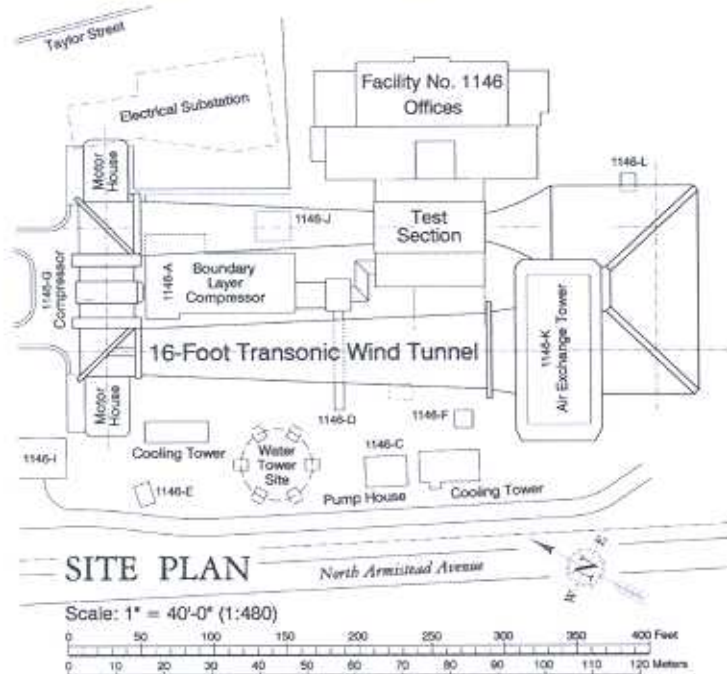
Building 1146

National Aeronautics and Space Administration - Langley Research Center
Hampton, Virginia

Construction of the 16-foot High Speed Tunnel (HST) was approved in 1939 at the recommendation of the Special Committee on Future Research Facilities to evaluate cowings and cooling capacities of full-size engines and propellers. Designed by David J. Biernmann and Lindsay I. Turner, Jr. the tunnel featured a single-return atmospheric circuit with a closed throat test section powered by a 16,000 horsepower motor and fan that could drive the system up to 533mph. Included were two propeller dynamometers of 2,000 and 6,000 horsepower capacities. The tunnel went into service December 5, 1941 and was immediately engaged in wartime testing of air-cooled aircraft engines. Its complement of thermocouples rapidly pinpointed cooling problems, and it was eventually used to test the aerodynamics of the first atomic bombs. Engineers noticed the tunnel tended to choke at 450 mph, and in 1947 Ray H. Wright's new discoveries in "slotted throat" designs were applied to a small parasitic test section which easily passed the speed of sound. Further tests at the 16-foot HST improved slotted-throat concepts, but the 8-foot High Speed Tunnel (Building 641, HAER No. VA-118-B) was the first to be completely upgraded for transonic testing. By December 1950, the 16-foot HST was refitted with two 34-foot diameter counter-rotating fans, each powered by a 30,000 horsepower motor and variable frequency power supply to achieve speeds up to 366 rpm. Air speed around Mach 1 was governed by air temperature, and adjustable vanes in the air intake and exhaust towers admitted as much as 20% outside air to control temperature in a range between 0 and 180° F. Additional improvements included a 14-foot octagonal slotted test section with adjustable walls whose slots encompassed about 1/8 of the test section periphery and offered a 22-foot long test region. Instruments included five 100-tube mercury manometers for measuring pressures on various points of models. Hot jet exhaust was simulated by the decomposition of hydrogen peroxide. Wire strain-gauge indicators transmitted load readings to various recording devices in a new control room outfitted with computers. Models were supported by an instrumented cantilever strut which could vary angles of

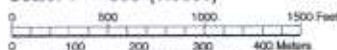
attack from -15° to +30°. A schlieren system visualized and photographed air flow. Air filters in the air exchange towers and acoustical baffles were also installed. The redesignated 16-foot Transonic Tunnel (TT) was active throughout the Cold War era, testing aircraft such as the B-58 Hustler, F-14 Tomcat, F-15 Eagle, F-18 Hornet, stealth F-117 Nighthawk, B-1 bomber, the Apollo spacecraft, Space Shuttle, X-33 VentureStar and the Navy Advanced Technology Fighter. During these aircraft programs the tunnel was upgraded repeatedly. In 1969 a 35,000 hp plenum blower was installed, and in 1977 the tunnel was fitted with new fan blades, plus new tunnel controls and control room equipment coupled with new computers and data monitors. A similar upgrade was undertaken in 1989-90 which also included a new model support system and process controllers to govern tunnel speed and the capabilities of powered models. The 16-foot TT presently provides testing facilities to private industry under the Wind Tunnel Enterprise program inaugurated in 1994.

These drawings were completed by Richard K. Anderson, Jr., of Cultural Resource Documentation Services, Sumter, SC for inclusion in the Historic American Engineering Record (HAER) of the National Park Service, U.S. Department of the Interior. The HAER program documents significant engineering and industrial sites throughout the United States. Project records are maintained in the Prints and Photographs Division of the Library of Congress. Mr. Anderson prepared these drawings under contract to the James River Institute of Archaeology (JRIA) of Williamsburg, VA (Matthew Laird, Senior Historian) with the assistance of Carol Tyrer. JRIA conducted the HAER documentation project for NASA Langley Research Center under contract to Science Applications International Corporation (SAIC), Hampton VA, which assists NASA in addressing environmental compliance requirements. Caroline Diehl of SAIC and Carol Herbert of Tessada & Associates assisted in identifying and copying numerous references and engineering drawings in support of this project. Matthew Laird composed the HAER data pages with input from David Dutton and Michael Newbill; Chris Cunningham of Richmond, VA prepared the large format photographs.



LOCATION MAP

Scale: 1" = 300' (1:3600)



Based on NASA Langley Geographic Information System map, October 2001.

UTM Coordinates: 18,378960,4105460

Scale: 1" = 20'-0" (1:240)

Scale: 1" = 20'-0" (1:240)

NASA LANGLEY RESEARCH CENTER RECORDING PROJECT
WATERBURY, WYOMING AIRFIELD
COUNCIL BEARING OBSERVATION OF THE AIRPORT

Advertisement

BUILDING #48, 11 WEST TAYLOR STREET
HARRINGTON

WILEY

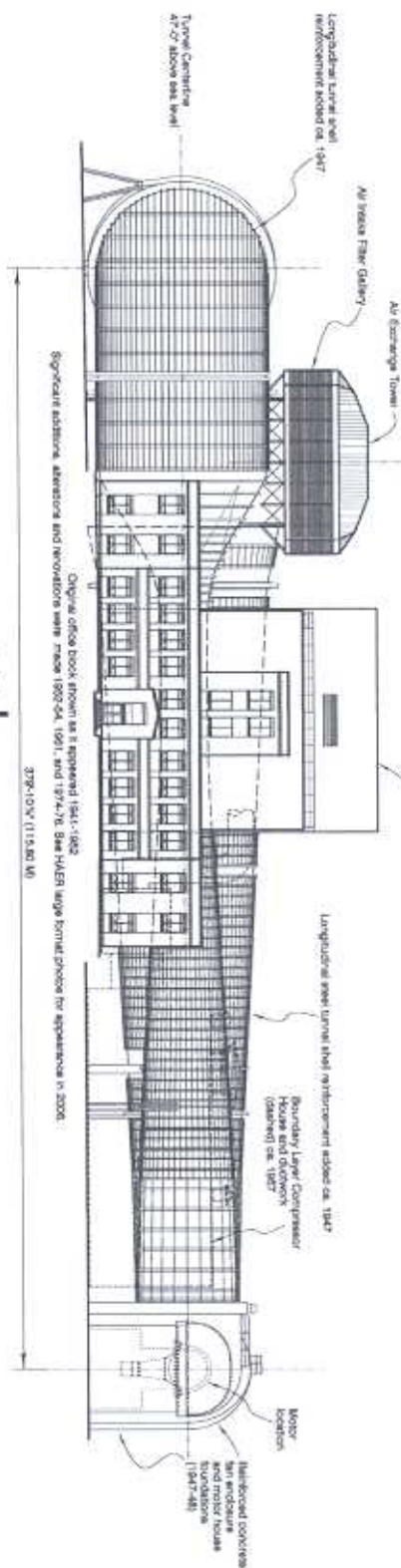
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THE PUBLIC AMERICAN
BUSINESS RECORD
VA-118-E

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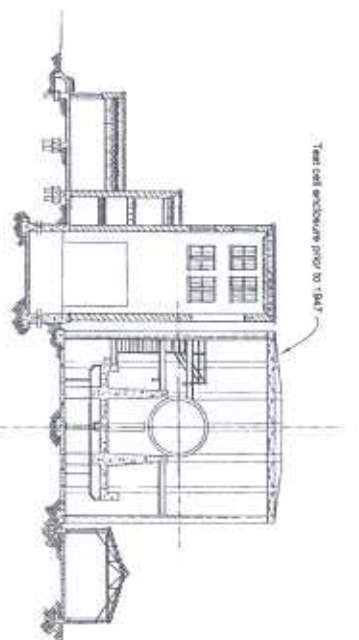
Steel structure of bar coil enclosure surfaced in Granite enclosure built 1947-48



EAST ELEVATION

Elevation based on NASA Langley Research Center drawings: LD-17474-16, LD-24, 640, LD-200, 381, LD-298, 395, LD-2195-6, LD-1, 209, 494, LD-1, 208, 626, LD-1, 208, 637, LD-1, 209, 698 and numerous interior and contemporary photographs.

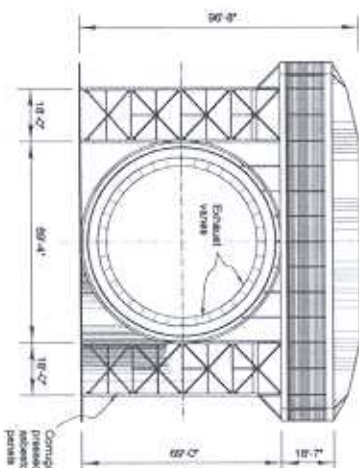
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SECTION A - A

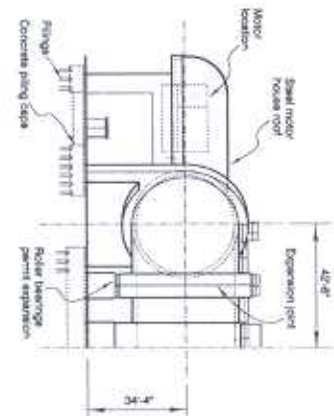
Section A-A based on drawing LD-1099-30 "18' Wind Tunnel Bldg. No. 1-48" Oct-1947

Scale: 1" = 20'-0" (1:240)



AIR EXCHANGE TOWER NORTH ELEVATION

Rebuilt from drawing LD-1098-657 "Elevation of Ventilation Tower" Oct. 1948 (1948)



NORTH END

MOTOR HOUSE & FAN UNIT

Rebuilt from drawing LD-17474-6 "Elevation of 18' F.H.S. Tunnel" 1950 (New & S.W.O.W. Sept. 1947 and LD-17474-1 "Elevation of 18' F.H.S. Tunnel - Drive Motor Enclosure" Oct. 1947)

DESIGNED BY: Richard K. Anderson, Jr., 2006.

NASA LANGLEY RESEARCH CENTER RECONSTRUCTION PROJECT
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
OFFICE OF HISTORIC PRESERVATION

HAMPTON

18-FOOT TRANSONIC WIND TUNNEL (1941)

BUILDING 114, 11 WEST TAYLOR STREET
HAMPTON

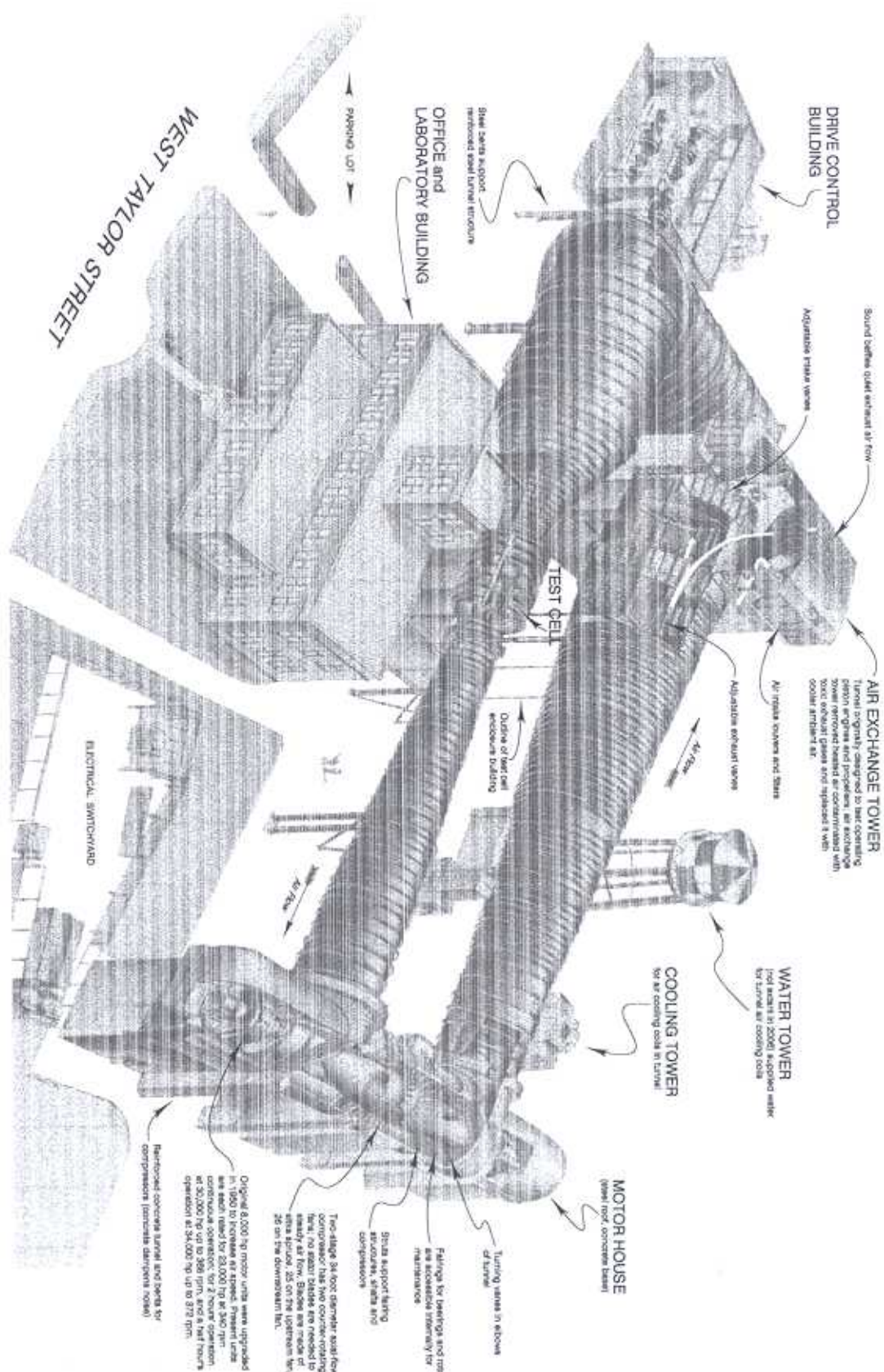
VIENNA

SHEET
1 - 4

HISTORIC AMERICAN
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IF REPRODUCED, PLEASE CREDIT: ARCHITECT: RICHARD K. ANDERSON, JR., 2006; NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, NASA'S OFFICE OF HISTORIC PRESERVATION, DATE OF THE DRAWING

CUTAWAY DIAGRAM of 16-FOOT WIND TUNNEL



Not Scale
Cutaway drawing based on sketch by M. Vogel, 1963, NASA Langley Research Center, drawing number 1-481-43 (NASA Doc E1-2005-00386-20).
Illustration based on material in NASA Technical Paper 2021, "The NASA Langley 16-Foot Transonic Tunnel: Historical Overview, Facility Description, Calibration, Flow Characteristics, and Test Capabilities," September 1995. Not shown are boundary air layer removal ducts and 56,000 hp compressor.